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Forensic palynology: Current status of a rarely used technique in the United States of America

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Abstract

The United States of America would seem to be an excellent location for using pollen data in forensic applications. The vegetation within the region is highly diverse ranging from areas of Arctic tundra to some of the most inhospitable deserts anywhere in the Western Hemisphere. The highly varied ecology, great plant diversity, thousands of vegetational microhabitats, and extensive published pollen records for the region provide an ideal setting for these types of analyses. This diversity, often characterized in most locations by unique combinations of pollen types, makes the use of forensic pollen a reliable technique that can often be used to associate individuals with a unique crime scene or geographical region. Nevertheless, forensic pollen studies in the United States of America are currently one of the most highly under utilized techniques available to assist in solving criminal and civil cases. During the past century there has been a very limited attempt to use pollen evidence in either criminal or civil cases, for a variety of reasons, including a lack of available information about the technique, a very limited number of specialists trained to do forensic pollen work, and an almost total absence of academic centers able to train needed specialists or forensic facilities able, or willing, to fund research in this area. Hopefully, this paucity of use will change if certain steps are taken to encourage the routine collection and use of pollen evidence in both criminal and civil cases.

Keywords: United States of America; Forensic palynology; Criminal and civil applications

1. Introduction

The United States of America (USA) is an ideal place to use forensic pollen data in solving both criminal and civil cases. In addition to thousands of microhabitats, each with their own unique blend of flora, there are a number of major ecotonal regions that vary from Arctic tundra to searing deserts to tropical rain forests. The country's vegetational diversity has been detailed in many extensive studies by botanists and ecologists [1–6]. Another key asset of the USA is its long and extensive record of pollen studies [7] that began with the first pollen analysis conducted in North America [8]. In addition to numerous pollen studies of vegetational changes during the late Quaternary, there are thousands of individual pollen studies of archaeological sites, surface sample transects, and extensive studies of the pollen found in honey samples from widely varied habitats in all regions of the country. Recently, John Williams and his colleagues (http://www.geography.wisc.edu/faculty/williams/data.htm) have posted an extensive database of over 4500 pollen analyses derived from surface samples examined throughout most regions of North America. This tremendous database of pollen information is already proving to be a key asset in determining the geographical location of some crimes, which were committed in one region of the country, but the suspects were apprehended in another region, sometimes hundreds or thousands of miles from the crime scene. The ease of movement throughout the vast region of the USA by vehicle, train, and air travel often creates a false sense of security for criminals who commit crimes in a region different from where they reside.

For those who are unaware of the flora and geography of the USA, it is useful to briefly describe the diversity and richness of these differences, which are both an asset, and sometimes a liability, in efforts to solve cases involving forensic pollen evidence. Previous pollen studies of surface soils and domestic honey from different regions of the USA demonstrate that each

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microhabitat produces its own unique pollen spectrum or ''pollen print'' as often called. A limited amount of these pollen data are already organized into databases, making it easy to find specific areas of the USA containing certain suites of pollen taxa. However, more work is needed to incorporate the pollen data from other surface and honey samples that currently exist only as data in articles published in journals, chapters in books, or as unpublished manuscripts.

In terms of area, the USA is the world's fourth largest country extending over more than 50° of latitude and over 120° of longitude. It consists of 50 individual states, 48 of which (continental states) are spread over a north-south distance of more than 2500 km between Canada and Mexico. The other two non-contiguous states include Alaska in the northwest corner of North America, and Hawaii, an archipelago of tropical, volcanic islands in the mid Pacific Ocean. The Continental USA is bordered along its eastern edge by the Atlantic Ocean. More than 4000 km to the west, the Pacific Ocean borders the states from Alaska in the north to California in the south. In between the east and west borders is a vast central plain, with high mountains in the west and hills and lower mountains in the east. The highest point is Mount McKinley in Alaska (6194 m) and the lowest point is in Death Valley, California (86 m below sea level).

No one vegetational classification scheme can justly describe the diverse flora of the USA with all of its microhabitats and varied terrain. Currently, the multi-volume series *Flora of North America* has consolidated much of the published literature on vegetational patterns and plant species from the USA. In an effort to provide the reader with a brief overview, we offer a short paragraph on a few of the major ecosystems, which illustrate the diversity and floral richness (Fig. 1).

1.1. Arctic ecosystems

The Arctic ecosystem (Fig. 1) that occurs in Alaska (and Canada), north of the Boreal Forest, is divided into two main regions, the High and Low Arctic [9]. High Arctic ecosystems are largely confined to areas where polar deserts are prevalent; none occur in the USA. Low Arctic landscapes, however, do occur in Alaska. Grass, sedge, and moss dominate the Low Arctic tundra region, and in the poorly drained areas across much of northern Alaska [10] shrubs such as *Alnus* (alder), *Betula* (birch), *Salix* (willow), wildflowers, grasses, and many species of Ericaceae, Empetraceae, and Diapensiaceae dominate.

1.2. Boreal Forest

The Boreal Forest (taiga) consists of evergreen coniferous forests that extend as a continuous band across much of the USA/Canadian border from Northern Minnesota eastward to Maine (Fig. 1). The North American taiga can be divided into seven distinct regions: Alaskan, Cordilleran, Interior, Canadian Shield, Gaspé-Maritime, Labrador-Ungava, and Northern Boreal Boundary [11]. Conifers that dominate the taiga include a number of species of *Abies* (fir), *Larix* (larch), *Picea* (spruce), and *Pinus* (pine). Shrub lands associated with this region are dominated by various species of Ericaceae, alder, birch, and willow. Bog and fen-type wetlands, common throughout the boreal forest region, are mostly dominated by *Sphagnum* moss and a diverse assemblage of Ericaceous shrubs. Other herbaceous flora in these bog and wetland regions include many species of composites, other types of wildflowers, sedges, orchids, and a wide variety of grasses [12].

1.3. Eastern Deciduous Forest

The Eastern Deciduous Forest encompasses a large section of the eastern USA from New York State south to Georgia and from Georgia westward through the South to East Texas (Fig. 1). The primary arboreal components include a wide variety of deciduous hardwoods with a complex mixture of shrubs, herbs, and grasses as part of the under story vegetation [13]. The region can be divided into eight specific areas, or associations each with a different composition of diverse herbaceous and shrub flora; however, all include a mixture of many hardwood species including genera such as: *Fagus* (beech), *Liriodendron tulipifera* (tulip tree), *Acer* (maple), *Tilia americana* (basswood), *Aesculus* (buckeye), *Quercus* (oak), *Liquidambar styraciflua* (sweet gum), *Fraxinus* (ash), and *Carya* (hickory). In prehistoric times, *Castanea dentata* (American chestnut) was a prominent member of these forests but the chestnut blight epidemic, which was first noticed in 1904, has killed most of them [14]. In disturbed or logged areas of the Eastern Deciduous Forest several different species of pine and *Juniperus* (juniper) are now quite common. In the northernmost areas of the Eastern Deciduous Forest one finds transitional plant communities where boreal conifers, such as *Picea glauca* (white spruce) (in the western fringes) and *Picea rubens* (red spruce) (in the eastern fringes), become important components while *Picea mariana* (black spruce) and larch tend to dominate the boggy regions within the fringe areas.

1.4. High Elevation Appalachian Ecosystem

The higher elevations of the Appalachian Mountains in the Mid-Atlantic States of the eastern USA contain a unique assemblage of sub-alpine and alpine vegetation (Fig. 1) [13]. Palynological evidence suggests that many species that are now present in the High Elevation Appalachian Ecosystem represent remnants of vegetations that are now restricted to more northern areas, but were present in the southern Appalachians 20,000 years ago during the last ice age. The High Elevation Appalachian Ecosystems can be divided into three distinct regions based on floristic differences between the southern and northern areas of the Appalachian Mountains. Commonly associated species in much of this ecosystem include *Abies fraseri* (Fraser fir), *Betula*, *Sorbus americana* (mountain ash), *Vaccinium* spp. (huckleberry), and *Viburnum* spp. (black haw). Grass and heath balds, which are the only treeless, upland vegetation areas in the southern Appalachians, occur on some mountaintops and along ridges between 1700 and 1800 m in four Mid-Atlantic States (Virginia, North Carolina, Tennessee,

	Artic Ecosystems		Desert
	Boreal Forest (taiga)		Mediterranean and Madrean Woodlands and Scrublands
	Eastern Deciduous Forest		Pacific Coast Coniferous Forest
	High Elevation Appalachian Ecosystem		Western Montane Coniferous Forest
	Southeastern Coastal Plain Ecosystem		Mosaic (desert scrubland, grassland, pinyon-juniper and Madrean)
	Grasslands		Madrean Woodlands and Scrublands

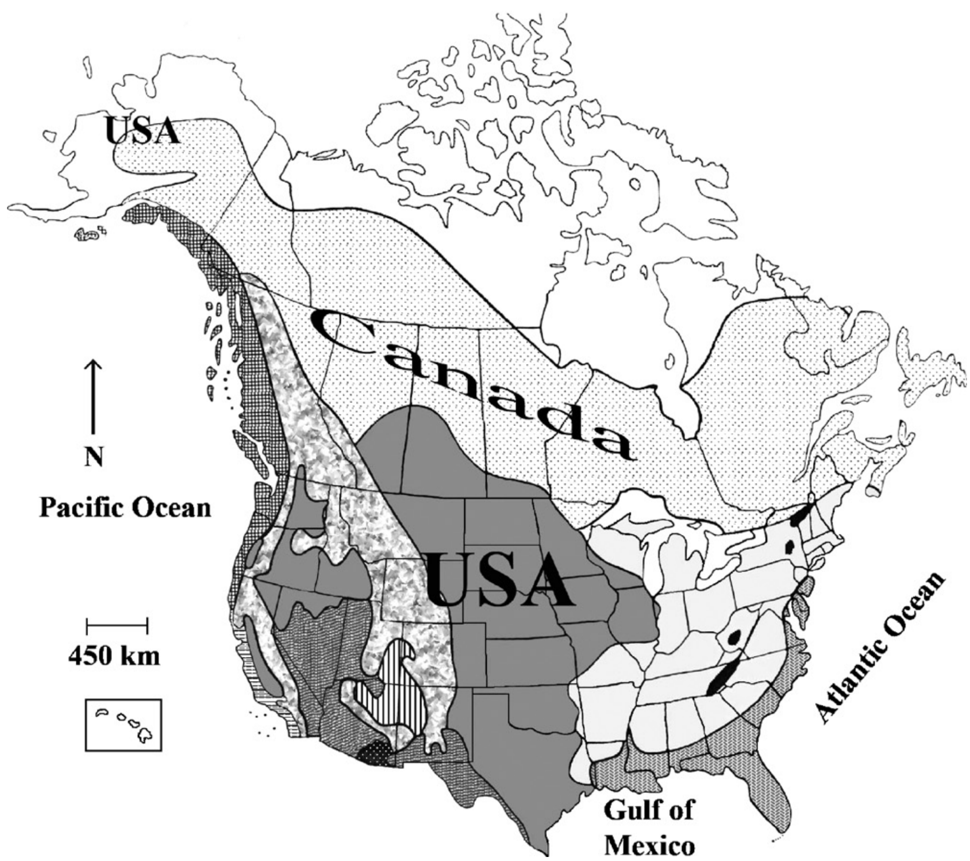

Fig. 1. Simplified vegetational map of the United States of America (USA) and Canada showing the different vegetational zones (modified from Barbour and Billings [5] and Barbour and Christensen [6]). Tidal Wetlands and the Beach and Frontal Dune Ecotone are not shown on the map due to their affinity to the coastlines. The Hawaiian Islands are not drawn to scale and all of them are not illustrated, and their ecological zones are not illustrated. Legend for the vegetational zones is shown in figure.

and Georgia). In the same regions, grass balds are found along some ridge crests between 1400 and 2000 m elevation [15–17].

1.5. Southeastern Coastal Plain Ecosystem

The Southeastern Coastal Plain is sometimes considered part of the Eastern Deciduous Forest (Fig. 1) [18,19]. Regardless, it is a diverse system with many isolated and unique floral habitats. It runs along the eastern coast of the USA from New Jersey south to Florida and then turns westward to Texas. The floral differences within this ecosystem allow it to be divided into five regions. Three of these include: the Tropical Hardwood Hammocks located at the southern tip of Florida [20–22]; Alluvial Wetlands consisting of river oxbows, swamps, backwater, and flat areas, and Paludal Wetlands (wet ''prairies'') consisting of bogs, peat lands, and lime sinks. Forest taxa help define each of the five regions. For example, various species of pines dominate the Upland Pine Forests regions, while hardwoods of oaks, *Magnolia grandiflora* (southern magnolia), *Fagus grandifolia* (American beech), *Ulmus* (elm), ash, sweet gum, and hickory dominate in the Upland Hardwood Forests [19]. Wetlands of the Coastal Plain are dominated mostly by grasses such as *Muhlenbergia* (muhly grass) and *Panicum* (panicum), and grass-like taxa including species of *Carex* (sedge), *Cladium* (saw grass), *Juncus* (rush), *Rhynchospora* (beakrush), and *Scirpus* (bulrush). The Peatland areas within the Coastal Plain are typically surrounded by a dense, impenetrable cover of deciduous and evergreen shrubs including *Cyrilla* (ti-ti), *Ilex* (holly), and *Lyonia* (lyonia) [23,24]. Bay Forests, dominated by trees such as *Gordonia* (bay), *Magnolia virginiana* (sweet-bay), and *Persea borbonia* (redbay), are common at the margins of bogs, in shallow peat areas, and around lime sinks.

1.6. Grasslands

The vast area of grasslands is perhaps the most extensive, and varied, vegetational ecosystem in the USA. They extend down the center of the country from Canada to Texas and from the west side of the Appalachian Mountains westward to the eastern foothills of the Rocky Mountains (Fig. 1). Grasslands also cover portions of the Pacific Coast states of California, Oregon, and Washington. Some of the major U.S. grassland regions include the Central Grasslands in the central core of the nation, which consist of three major types of prairies (tall-grass, mixed-grass, and short-grass), the Central California Grasslands, and the Intermountain Grasslands, which include regions of southwestern Idaho, northern Nevada, eastern California, and portions of Oregon and Washington State east of the Cascade Mountains. Throughout the grassland region the primary vegetation is dominated by diverse species of grasses and sedges mixed with a wide variety of herbaceous plants and wildflowers, often reflected by a myriad species of blooming composites and legumes. It is estimated that more than 7500 distinct plant species live in the North American Grasslands Region [25].

1.7. Desert Scrub

The Desert Scrub ecosystem includes four USA deserts: Chihuahuan, Sonoran, Great Basin, and Mojave (Fig. 1). The easternmost and largest of these deserts is the Chihuahuan Desert that begins in West Texas and runs westward through most of the southern part of the state of New Mexico. Common taxa include: *Larrea tridentata* (creosote), *Acacia* spp. (acacia), *Prosopis* spp. (mesquite), *Agave lecheguilla* (lechuguilla), *Dasylirion* spp. (sotol), *Dalea* (prairie clover), *Ephedra* spp. (joint-fir), *Fouquieria splendens* (ocotillo), *Jatropha dioica* (leather-stem), *Opuntia* spp. (prickly-pear), and *Yucca* spp. (yucca). Lechuguilla is one of the more common plants and it is considered to be the indicator species for the Chihuahuan Desert [26–28]. Beginning a little further west in southwestern Arizona is the Sonoran Desert that continues westward into southeastern California. The Sonoran Desert is known for its richness of cactus species and the saguaro, *Carnegiea gigantea*, which is considered to be its indicator species. Along a band extending eastward from the border of California through southern Nevada and into southwestern Utah is the smallest of the four U.S. deserts, the Mojave Desert. This desert is famous for its Joshua-tree (*Yucca brevifolia*), which is considered to be its indicator species. Other prevalent desert vegetation in the Mojave area include species of joint-fir and a variety of cacti including *Echinocactus polycephalus*, *Ferocactus cylindraceus* (*F. acanthodes*), and prickly-pear [6]. The final desert, the Great Basin, lies within a giant circle extending from central Nevada eastward through central Utah, down to southwestern Colorado and into the northern parts of New Mexico and Arizona. The Great Basin Desert is classified as a cold desert because it occurs at higher elevations (1200–1600 m) than do the other three. Common taxa in the Great Basin Desert include woody perennials such as *Chrysothamnus* (rabbit brush), *Ephedra* (joint-fir), *Purshia* (cliff-rose), *Atriplex* spp. (salt bush), *Artemisia* (sagebrush), and *Sarcobatus* (greasewood). Normal succulent species found in the other three deserts are uncommon to the Great Basin region [29–32].

1.8. Mediterranean and Madrean woodlands and scrublands

Mediterranean and Madrean ecosystems occur in some areas of the West Coast of the USA (Fig. 1). According to Cody and Mooney [33], Mediterranean ecosystems are found in California and five other locations throughout the world where each of them shares many common characteristics (i.e., all occur north or south of the equator between 40° and 32° latitude, all occupy the west or southwest edges of continents, and all have hot, dry summers). The closely related Madrean ecosystem vegetation in the USA occurs only in limited areas of central and southwestern Arizona [34–38]. In the USA, the Mediterranean and Madrean vegetations include a mixture of evergreen forests, oak woodlands, savannas, grasslands, and several types of scrublands [6]. A number of species of oaks are the indicator species for these areas of the USA where oaks are commonly associated with other key taxa including maple, *Arbutus* (madrone), *Ceanothus* spp. (jersey tea), *Garrya* spp. (silk-tassel), *Rhamnus* spp. (buckthorn), *Rhus* spp. (sumac), and pines [39,40].

1.9. Pacific Coast Coniferous Forest

A luxuriant and productive coniferous forest exists in a narrow band along the Pacific Coast of the USA from the coastline inward to the western edges of the Northern Coastal, Cascade, and Southern Coastal Mountains (Fig. 1). This ecosystem begins around Cook Inlet, near Anchorage Alaska, and runs southward along the ocean front down to Monterey County, California [41,42]. This region is dominated by a rich diversity of large, long-lived tree species, and an equally rich shrub, herbaceous, and cryptogam (mosses, liverworts, ferns) understory. The area has a mild, maritime climate where hard frosts and persistent snow are uncommon and where hardwoods are rare [6]. The coniferous forest zone extends along the coastline for more than 1500 km and can be characterized by three similar, yet slightly different, zones [41]. In the northern and central part of this ecosystem hemlock (*Tsuga heterophylla*) is the dominant species. Other conifers associated with the hemlocks include: Alaska-cedar (*Chamaecyparis nootkatensis*), Sitka spruce (*Picea sitchensis*), Douglass-fir (*Pseudotsuga menziesii*), pacific silver fir (*Abies amabilis*), western red cedar (*Thuja plicata*), and mountain hemlock (*Tsuga mertensiana*). Common members of the understory vegetation in these zones include dogwood (*Cornus canadensis*), blackberries and raspberries (*Rubus*), blueberries, and a thick carpet of different species of ferns and mosses. In the southern part of the Pacific Coast Coniferous Forest Zone (Oregon south to California), the forest is dominated by giant redwoods (*Sequoia sempervirens*) with associated species of grand fir (*Abies grandis*), Douglass-fir, and western hemlock (*Tsuga heterophylla*) [41,43].

1.10. Western Montane Coniferous Forest

Most of the mountain ranges in the western half of the USA are dominated by coniferous forests (Fig. 1). Conifer forests are the primary vegetation types found throughout the Rocky Mountains in the western central region of the continent; in the Coastal Range of Washington, Oregon, and northern California; in the Transverse and Peninsular Mountain ranges of southern California; and at higher elevations in smaller, scattered mountain ranges and northern plateau regions of the intermountain West. Common throughout these conifer forest ecotones is a zonation of forest taxa that are sensitive to elevation gradients [44], with similar zone components found in a number of separate mountain chains. Zonation in the southern portion of the Rocky Mountains begins with pinyon-juniper woodlands at the lower elevations (800–1500 m) that consist of several species of *juniper* and haploxylon pinyon pines (*Pinus cembroides*, *P. edulis*) in areas of Arizona, New Mexico, and Colorado. The next higher zone is the ponderosa pine (*Pinus ponderosa*) parkland, followed at higher elevations by thick forests dominated by Douglass-fir with associated taxa of white fir (*Abies concolor*) and blue spruce (*Picea pungens*). At the highest elevations, forests of shore pine (*Pinus contorta*) grade into thin zones of fir-spruce, sub-alpine forests mixed with small patches of bristlecone pine (*Pinus aristata*) growing in open and exposed areas near the upper limits of the tree line.

1.11. Tidal Wetlands

Along the Atlantic and Gulf Coasts are a number of tidal wetland areas containing about 347 different plant taxa. There are other tidal wetlands along the USA Pacific Coast, including coastal areas in the Arctic regions of Alaska [45]. In general, the Tidal Wetlands consist mostly of salt marshes and coastal meadowlands that are periodically flooded, are restricted to shorelines, and exist in areas with low-energy waves [46].

The vegetation of the Tidal Wetlands can be divided into two primary zones. The Low Marsh zone exists in narrow bands, generally no wider than 30 m from the water's edge. Behind these coastal Low Marsh zones are the High Marsh zones that are much wider and in some areas can be thousands of meters wide [47]. Plant dominants in the Tidal Wetlands depend on the geographic location of the salt marsh. For example, in the Arctic regions, the High Marsh zone consists of a mixture of saltbush, sedge, *Festuca* (fescue), *Plantago* (plantago), *Ranunculus* (buttercup), *Salicornia* (saltwort), bulrush, and *Suaeda* (sweepweed) [48,46,49–53]. South and east of this region, along the U.S. Atlantic Coast, the High Marsh zones are dominated by salt meadow cord-grass (*Spartina patens*), with salt grass (*Distichlis spicata*), spikerush, saltwort, and sweepweed [54,46,49,45,55]. Along the shoreline of the Gulf of Mexico in the states of Florida, Alabama, Mississippi, Louisiana, and Texas, cord-grass dominates the Low Marsh areas while behind them the High Marsh areas are dominated by beakrush, saltwort (*Batis*), sedges, *Distichlis spicata*, bulrush, saltmeadow cord-grass and sweep weed [56,46,47,57]. Along both the Atlantic and Gulf Coast areas of southern Florida below 29°N latitude, are unique regions of thick groves of mangroves that form the dominant vegetation in shallow bays and coastal marshes [58].

1.12. Beach and Frontal Dune Ecotone

The final ecotone is the Beach and Frontal Dune Ecotone characterized by maritime climates that are exposed to salt spray, have soils with a low water-holding capacity, and consist of shifting sand dunes. Many plants living on these beach and dune habitats have a wide latitudinal distribution along the coastal regions of the USA [59–62]. The vegetation growing on the Pacific Coast beaches and dunes varies from the other beach regions found at lower latitudes (24° N), and from those characterized by Arctic and Sub-arctic taxa at higher latitudes (54° N) [63,64]. Along the Gulf of Mexico, 73 common taxa form the major vegetation [61]. Sea-oats (*Uniola paniculata*) dominates everywhere along the Gulf Coastal region except in Louisiana, where it is replaced by a dune ecotype consisting of salt meadow cord-grass. Several of the plant taxa common to the Gulf Coast beaches and dunes continue around the Florida peninsula and up along the Atlantic Coast as far north as the Virginia–North Carolina [65–68]. The Mid-Atlantic Beach and Frontal Dunes are dominated by beach grass (*Ammophila breviligulata*) [6]. The Beach and Frontal Dunes of the Great Lakes system include beach grasses, sea rocket (*Cakile*), seaside spurge (*Euphorbia polygonifolia*), and Russian thistle (*Salsola kali*). Behind the dune ridges in many areas of the Beach and Frontal Dune Ecotone are regions of grassland-heath scrub containing tall grass prairie grass species such as big bluestem (*Andropogon gerardii*), yellow Indian grass (*Sorghastrum nutans*), and spear grass (*Stipa*). Also common to the grassland-heath scrub region are shrubs that include species of manzanita (*Arctostaphylos*), juniper, and plum (*Prunus*) [69–72].

The Hawaiian Islands are a chain of over a hundred islands, reefs, and shoals that stretch over 1500 miles (2400 km) southeast to northwest. The ecosystems of Hawaii are very different from that of the rest of the USA. Lowland forests on the windward coasts of the islands gradually change to the rain forests at moderate elevations and to patches of tundra on the summits of the highest peaks. Vegetational zones of the Hawaiian Islands include tropical coastal vegetation, lowland wet forests, montane wet forests and bogs, montane dry forests, alpine vegetation, grasslands, and shrub lands. Because of the isolation, terrain, soil, etc. many unique plants occur here. For example, the Haleakala Silversword (*Argyroxiphium sandwicense*) is found only in the crater and on the slopes of the Haleakala Volcano.

With such a diverse geography, topography, and vegetation, the USA is an ideal location for the use of forensic pollen studies. Nevertheless, forensic palynology appears to be a technique few people know about and a science that even fewer are willing to utilize. After searching for forensic pollen literature published in the USA, and after contacting most of the major forensic facilities in the USA, forensic palynology and its techniques are virtually unknown to most law enforcement agencies and that few palynologists in the USA have had any experience with these types of studies.

Over a decade ago, Bryant et al. [73] mailed written questionnaires to police departments and forensic laboratories in each of the 44 largest metropolitan areas in the USA, and to the Federal Bureau of Investigation, the Central Intelligence Agency, and the Office of U.S. Customs. None (0%) of the respondents said they knew of any criminal or civil cases in which pollen evidence had been successfully used to prove or disprove a case.

A recent telephone and email survey of active and retired palynologists working in the USA revealed that only a very few of them had any experience using pollen as a forensic technique. In a few cases (discussed later), different retired palynologists said that they had very limited experience in this field during their career and that in each case their experience focused a single case. Prior to 2005, only a small number of active palynologists (mentioned later) working in the USA have had any experience using pollen as a forensic tool.

The terrorist bombing of the World Trade Center in New York City on September 11, 2001, changed the attitude of many people about the future and safety of locations not only in the USA, but also throughout the world. The subsequent formation of the U.S. Department of Homeland Security and the efforts of state and other federal agencies are now more clearly focused on trying to prevent future acts of terrorism. Many USA federal agencies have also taken steps to provide more effective methods of sealing the border areas and requiring more detailed information from visitors and immigrants. Nevertheless, these changes have had little effect on the use or acceptance of forensic palynology.

To our knowledge, the facilities at Texas A&M University are the only place in the USA where forensic pollen studies are currently being conducted on a fairly regular basis. Assets that make this possible include our modern pollen reference collection of nearly 20,000 taxa, our extensive library of published pollen keys and pollen atlases from many regions in the world, and the experience of our personnel who have been working in the field of general palynology and forensic palynology for over three decades.

2. Historical review of forensic palynology in the United States of America

2.1. The 1970s

The first forensic case that personnel from Texas A&M University were asked to investigate began during the mid 1970s. At that time the USA had a federal subsidy program designed to encourage beekeepers to maintain or expand the number of their hives. Honeybee pollination is essential for many agricultural crops grown in the USA; however, moving large numbers of bee hives from one orchard to another to ensure ample pollination is time-consuming and expensive. Often, beekeepers are paid very little for this service. Their main benefit comes from selling surplus honey made by their honeybees that visited the large numbers of flowers containing nectar and pollen. During most of the 1970s world prices for honey were low and without some price guarantee, beekeepers were reluctant to engage in the time-consuming task of moving hives, sometimes hundreds of miles, from one field or orchard to another. The United States Department of Agriculture (USDA), with funding authorized as part of the federal subsidy program, guaranteed beekeepers a stable price for their honey, which was higher than the existing world market price. This was an ideal situation for beekeepers, but to qualify for participation, only honey produced within the USA was eligible for sale to the government at the higher subsidy prices.

The Office of the United States Inspector General is charged with ensuring that commodities sold to the government under the various agricultural subsidy programs were from domestically produced products. Routine testing is one way to ensure this type of compliance. Beginning in 1975, samples of honey purchased as part of the federal subsidy program were sent to the Texas A&M Palynology Laboratory for pollen studies to determine the floral sources and geographical origin of each sample. During the next 5 years additional honey samples purchased as part of the subsidy program were selected and sent for pollen analysis. In most cases, the only information received with each honey sample was a federal lot number and the government's expectation that all samples came from some USA location.

Almost immediately, it was realized that we faced the daunting task of trying to pinpoint precise geographical locations with the USA based only on the pollen found in a given honey sample. For a number of other countries [74] that task would not have been difficult because extensive pollen studies of honey already existed and key pollen databases for those countries were already available. However, by the 1970s very little pollen research had been completed on USA domestic honey [75]. Aside from a few very preliminary studies conducted during the early 1900s, the only major pollen studies of USA honey were those completed by Lieux [76–80] for areas of Louisiana and Mississippi.

In establishing a baseline for honey identification in the USA, over 500 honey samples were collected by the USDA from known geographical localities in all but three of the 50 states. The samples originally had been used for sugar isotope studies of honey but funding cuts prevented the second phase of the study, the pollen studies. With grant funding from the U. S. National Honey Board, those samples were used to form the beginning phase of a pollen database for domestic honey.

The initial studies, which were part of the honey subsidy program, revealed that most of the purchased samples had come from domestic regions. However, about 6% of the examined samples matched pollen spectra found in the honey database of samples from regions of Yucatan, Mexico, and other regions of Central America. During the 1980s and 1990s the world price for honey rose faster than the federal subsidy price. As a result, little honey was sold to the federal government and their need for verification ended.

From examining unpublished reports and from conversations with field agents who work for the USDA, it seems that nearly all of the early pollen forensic studies in the USA focused on law suits involving beekeepers. One case occurred during the early 1970s in Michigan, near the USA–Canadian border. At that time there was an outbreak of bee mites in the southeastern USA and Michigan imposed an embargo on importing hives or honeybees into their state from any other locale unless they were inspected for mites. A local beekeeper with over 100 hives was suspected of illegally importing additional beehives into Michigan without having them inspected and certified. Using a search warrant, a USDA agent removed honey samples and some of the bees from each of the suspected hives. The bees were mite free, but pollen studies of the honey contained floral types common to the southeastern USA, but not known to grow in Michigan.

In a similar case from the nearby state of Pennsylvania, a beekeeper with a large number of hives sued a neighboring farmer because he believed his honey supply had been ruined by insecticides that had been sprayed on a nearby lima bean field. The beekeeper's law suit argued that his honeybees were collecting nectar contaminated with insecticides from the bean flowers and then returning to their hives where it was mixed with other nectars in the production of honey. However, studies of the produced honey and of pollen loads recovered from honeybees returning to the hives revealed that the bees were not foraging on the lima bean flowers. Instead, the pollen data revealed that the bees were foraging on a variety of other nectar-producing flowers closer to the hives.

Another early use of pollen in a forensic case occurred during the late 1970s, when a sample of illegal marijuana was seized from a suspected drug dealer in Texas. Law enforcement officials wanted to know whether the marijuana sample had been grown locally, or whether it had been imported from foreign or out-of-state sources. If imported, they hoped to learn the source region and perhaps how the marijuana had been transported into Texas. Our pollen studies of the sample provided some answers, but we were not able to pinpoint the precise source location. Our study revealed the sample was dominated by ragweed-type pollen (*Ambrosia* sp.) and marijuana (*Cannabis sativa*). Other pollen types included Cheno-Ams pollen (a name given to the nearly identical pollen types from the Chenopodiaceae family [goose-foot family] and *Amaranthus* [pigweed]), several different types of grass pollen, willow (*Salix* sp.), wild buckwheat (*Eriogonum* sp.), plantain (*Plantago* sp.), honeysuckle (*Lonicera* sp.), several species of composite pollen, juniper, and a number of small haploxylon pine pollen grains. The only small haploxylon type pine pollen found in the USA comes from pinyon pine trees (*Pinus cembroides*, *P. edilus*) that grow in some areas of West Texas and throughout the American Southwest (Arizona, New Mexico, etc.). The pollen concentration revealed an average of 105,228 pollen grains per gram, which is not unexpected, considering that both ragweed and marijuana plants are very prolific pollen producers. However, the pollen concentration value suggested the sample may have been grown in a forested or grassland region rather than a desert area where pollen concentration values tend to be very low [73].

There was very little arboreal pollen in the sample, except for pine, suggesting the marijuana had probably been grown in an open grassland or scrubland type environment rather than in a forested or riparian region. An absence of gum tree pollen (*Eucalyptus*, *Melaleuca*) ruled out areas of southwestern Arizona and southern California where those imported trees are now quite widespread and prolific. An absence of arboreal pollen types from many of the common deciduous trees (i.e., *Quercus*, *Carya*, *Celtis*, *Fagus*, *Juglans*, *Ulmus*, diploxylon *Pinus*, *Fraxinus*), ruled out the southeastern USA area as a probable source. Also missing from the sample were pollen types common to regions outside the USA. Therefore, based on comparative pollen data from surface samples available for many regions of the USA, and other data from marijuana samples, it was concluded that the sample had not been grown in some foreign locale. Instead, the sample was probably from a local Texas source area, probably someplace in the central or western part of the state.

2.2. The 1980s

Throughout the 1980s attempts were made to convince state and federal law enforcement agencies about the potential benefits of using forensic pollen studies. Lectures were presented at meetings of law enforcement agencies, stressing topics such as the importance of sample collection techniques, how to prevent subsequent contamination, and the importance of contacting appropriate specialists as soon as possible. Although these presentations were generally greeted with considerable enthusiasm and interest, very few law enforcement personnel contacted us with questions or with requests for assistance. Unfortunately, most of the contacts and most of the questions asked about the potential use of pollen data came too long after a crime had been committed. In other cases, potential evidence saved at a crime scene had subsequently been compromised by contamination. Nevertheless, there were a few cases in the USA during the 1980s, in which forensic pollen evidence did play an important role.

During the mid 1980s, the body of a murdered Hispanic man in his twenties was found in a ditch under some mesquite (*Prosopis*) bushes by the side of a dirt road near an interstate highway in West Texas. A crime scene investigation and subsequent autopsy reported that all identification labels had been removed from the victim's clothing, that the victim's face had been beaten, and that his hands had been cut off to prevent fingerprint identification. The autopsy also noted 21 stab wounds in the chest and torso region. No blood had been spilled at the crime scene so it was determined that the victim had been killed elsewhere and the body was then discarded by the side of the dirt road. No other clues were found at the crime scene other than the body. With nothing else to work with, and with no missing person's report from Texas that matched the victim, the investigators were unable to determine either where the crime had been committed, or where the victim may have lived. With no leads, and no way to determine the identity of the dead victim, after 6 months the evidence was filed and the case was listed as being unsolved. Months later, the lead investigator in the case attended a forensic conference at which a lecture was presented on the use of pollen as a forensic tool. After the lecture, the investigator asked if the case could be reopened and evidence searched for potential pollen clues associated with the crime.

Fortunately, during the autopsy the murdered victim's clothing has been removed and sealed in sterile, plastic bags. The bags had not been opened again. Before examining the clothing evidence, however, it was necessary to obtain a series of control surface samples at the location where the victim's body had been [81]. Control samples are necessary to understand what the normal pollen rain for the crime scene region might be and to get an indication of the types and percentages of local pollen taxa. It is also important to note which pollen taxa were coming from plants missing in the local environment, and thus could be assigned to the long distant transport category [82].

The surface control samples were collected using standard procedures that were altered slightly from those recommended by Horrocks [83]. One control sample consisted of 15–20 pinches of surface dirt each collected from a different location within a circle that was 5 m in radius moving outward from the body's location. During this collection we used sterile surgical gloves to pick up each pinch of surface soil from each location. All pinch samples were placed in the same sterile, plastic, zip-lock bag. After all pinch samples from one control sample had been collected, the plastic bag was sealed and the sample was shaken lightly to ensure uniform mixing. Composite-type control samples are collected because Adams and Mehringer [84] and Horrocks et al. [85] noted that these types of control samples, collected properly, provide fairly reliable records of the pollen rain at a given locale. After each control sample was collected, the bag was labeled with a permanent-ink felt tip pen, sealed, and was then placed into another plastic bag and sealed to ensure against possible contamination. Four additional control samples were collected in the same manner, each from areas approximately 100 m away from the body in each of the four cardinal directions. A clean pair of gloves was used for each control sample. Unlike the first, small collecting area, each of the new collection areas was approximately 50 m in diameter. In addition to collecting control samples, the types and percentages of the local vegetation in each control area were listed and photographs of each location were taken.

When the sealed plastic bags arrived from the coroner the items of clothing were removed and seven samples for analysis were collected. Five samples were properly collected from different areas of the victim's canvas tennis shoes: four of these came from different areas of the bottom tread of both shoes and from a muddy spot on the canvas surface of the left shoe. We collected one sample from the victim's shirt and the final, seventh sample from his pants. It was fortunate to recover enough pollen from each of the seven samples to count between 200 and 300 pollen grains per sample. This enabled a statistical comparison of the pollen data from the victim's clothing to those pollen data obtained from the five control samples.

As a group, all seven forensic samples from the victim's clothing were similar. When the pollen data from those samples were compared with the pollen from the control samples, some significant differences became obvious [86]. As a group, each of the control samples contained a similar type of pollen spectrum with approximately 5–7% *Juniperus* pollen but none of the clothing samples had more than 1% *Juniperus* pollen. The control samples contained an average of 40% Cheno-Ams pollen, while the average amount on the victim's clothing was twice that amount or about 80%. All of the samples from the victim's clothing contained some traces of *Cannabis* pollen whereas only one of the control samples contained one *Cannabis* pollen grain. None of the control samples contained alder (*Alnus*) pollen, but we found a few *Alnus* pollen grains in the sample from the victim's shirt. Finally, none of the control samples contained the pollen of buffalo berry (*Shepherdia argentea*), but we found several of these pollen grains in the shirt sample.

The pollen data from the victim's clothing and tennis shoes, when compared to the pollen data recovered from the five control samples, suggested that the victim had not come from the region where he had been found. Available pollen data from surface pollen studies in other locations of North Texas and the Midwestern USA confirmed that the victim most probably came from some locale in that region. Perhaps he had lived and then was killed in that region, before his body was transported to West Texas where it was dumped by the roadside. The lower percentages of juniper pollen, higher percentage of Cheno-Ams pollen, and traces of alder pollen are common in surface samples from North Texas and southern Kansas. In addition, the presence of buffalo berry pollen on the victim's shirt, which is from an insect-pollinated plant that does not grow in Texas, suggested the victim, came from some region north of Texas. The marijuana pollen on the victim's clothing suggested the possibility of his involvement in the illegal drug trade. Although our forensic pollen study of the clothing and tennis shoes from this victim did not solve the case, it suggested that the search for the victim's identity, and for his murderer, should focus on areas to the north of Texas in the Midwestern region of the USA instead of to the south, where investigators had previously searched, assuming the victim was an illegal Hispanic immigrant from Latin America. Nearly a year, later drug agents made a significant bust of an illegal drug network operating in Kansas, a Midwestern state. Although the murdered victim and the drug dealers arrested in Kansas were never directly linked, authorities remain convinced the victim was part of that network, or was killed by someone in that network.

Another application of forensic palynology during the 1980s occurred in the eastern part of the American Midwest. The case involved a victim who was kidnapped, robbed, and then murdered. The victim's car was stolen, but later abandoned when it got stuck in mud near a busy highway. The next night a drifter was arrested in a nearby town for breaking into a closed store. While in jail awaiting trial, the drifter told a fellow prisoner he would not be in jail if his car had not gotten stuck in the mud some 30 miles south of town. The other prisoner, hoping to work a deal for a lighter sentence, told this story to the sheriff. Based on this new information, the drifter was returned to the crime scene where the car was abandoned. He was also returned to the farm where the murdered victim had been kidnapped and his car stolen. However, even under intensive questioning, the drifter admitted nothing that would link him to the crime.

During the investigation of the crime scene, one of the law enforcement agents noticed that there was a large field of maize (*Zea mays*) growing between the dirt road, where the stolen car had been abandoned in the mud, and the nearby highway leading to the next town. The investigator wondered if traces of torn maize leaves on the suspect's clothing might link him to the crime scene. Fortunately, the drifter's shirt and pants had been removed and stored in plastic bags when he was arrested. As with all prisoners in that region, he had been given a pair of orange overalls to wear while in jail.

The shirt and pants were sent to a botanist who was asked to search for traces of maize leaves on the clothing. The botanist was also a palynologist, and thus also collected samples for pollen studies. The pollen samples provided the best results. The samples collected from the suspect's shirt revealed that the neck and shoulder region of the shirt had high concentrations of fresh maize pollen. The forensic sample collected from the pants also contained maize pollen, but in a lower percentage. The forensic pollen data indicated that the drifter had recently walked through a maize field, similar to the one between the abandoned car and the highway. As he walked through the field, he had brushed against blooming male tassels on the maize plants that were about head high. This accounted for the high amount of maize pollen found on the shoulder and neck area of the shirt. Lesser amounts of maize pollen also fell on his pants as he walked through the field. This evidence, combined with several eyewitness accounts from neighbors who remembered seeing the drifter walking along the highway trying to hitch a ride, confirmed that the drifter had been in the area where the murder was committed and where the car had been abandoned. While awaiting trial, additional evidence and several fingerprints from the victim's farm also linked the drifter to the murder.

2.3. The 1990s

Similar to efforts during the previous two decades, we continued to stress the importance and usefulness of forensic pollen studies. Nevertheless, few law enforcement agencies seemed to be interested. Only a few attempts to utilize this technique occurred in the USA during the 1990s.

In an effort to search for reasons why few law enforcement agencies are interested in forensic palynology, questionnaires were prepared and mailed to police departments and forensic laboratories in each of the 44 largest metropolitan cities in the USA. Copies were also sent to the forensic lab at the Federal Bureau of Investigation, and to various regional offices of the U.S. Customs. Of the mailed surveys, we received a 65% response rate (which is considered good for this type of survey). Of the completed surveys that were returned, only 6% indicated they knew that pollen could be used as a forensic tool and only 3% said they ''thought'' they remembered some criminal case in which pollen forensic work had been attempted. However, none (0%) of the respondents knew of a specific case where pollen was used as evidence.

During the early 1990s, most of the active palynologists in the USA were surveyed and asked if they had ever conducted a forensic pollen study or if they knew of any colleagues who had conducted any. One person who responded with a ''yes'' was Alan Graham, a professor of botany, who during the early 1990s was asked to help another palynologist, Walter Lewis, resolve the cause of an airplane crash in New Mexico [87–89].

The airplane, a twin engine, Beechcraft Super Kingair F90, left San Diego, California, on December 2, 1989, with the pilot and one passenger on a flight to Ruidoso, New Mexico. As the plane approached the Ruidoso airport the visibility was poor, there was a low cloud ceiling of only 250 m, and blowing snow. The pilot was inexperienced and when the plane emerged below the clouds it was off course and headed directly downward. The plane crashed and both occupants were killed. An investigation by the United States National Transportation and Safety Board removed the plane's two engines and sent them to the factory for examination. No defects were found and the investigation was closed and listed as ''pilot error.''

A year after the crash, attorneys representing the children of the crash victims filed a law suit against the engine manufacturer claiming that plant particles sucked into the motor during the flight were not caught by filters, and thus clogged critical fuel lines resulting in the lost of power and the crash. A small mass of plant material 4 mm in diameter, found in the B2 fuel line elbow, was carefully removed and divided equally between the plaintiff and defendant for examination. As the defendant, the airplane engine manufacturer hired a team of forensic scientists to examine the removed plant material and try to determine its origin. Drs. Graham and Lewis were members of that forensic team.

During Dr. Lewis' preliminary examination he discovered that 98% of the pollen found in the plant mass from the B2 fuel line consisted of two insect-pollinated types: curlycup gumweed (*Grindelia squarrosa*) and clover (*Melilotus officinalis*). The remaining 2% of pollen also came mostly from insect-pollinated types such as golden crownbeard (*Verbesina encelioides*) and red false mallow (*Sphaeralcea coccinea*). Only 0.1% of the total pollen in the sample came from any wind-pollinated plants (pine). As a result of these findings and other studies of material from the fuel line and engine, Graham, Lewis, and others on the forensic team concluded that the open fuel line on the abandoned engine, stored in an outdoor scrap pile, had become the home and pollen storage location of a small, solitary bee, *Ashmeadiella meliloti*.

The court found in favor of the defendant and agreed that the plant material found in the fuel line had come from subsequent sources and had not caused the crash.

Another of the few forensic pollen studies attempted during the 1990s was conducted by Ed Stanley of the New York City Forensic Laboratory [90]. During a raid, authorities seized a cocaine shipment but obtained little information from those in possession of the illegal drugs. After the raid, 124 g of a larger seized shipment of cocaine hydrochloride was sent to the New York City forensic lab for study. A member of the forensic lab, Ed Stanley, suggested they try to conduct a pollen analysis. His subsequent pollen analysis of the cocaine revealed three distinctly different groups of pollen present in the single sample. He determined that one group of pollen came from plants he suspected grew in the montane regions of Bolivia or Colombia below 2000 m. He was unable to identify many of the pollen types in that group because he lacked appropriate pollen reference materials from the region. However, he did note that the ektexine on some of the pollen grains was altered and that none of the pollen grains contained cytoplasm. He assumed that the pollen in that group undoubtedly became mixed with the coca leaves when they were being picked, or were airborne pollen contaminants that fell into the open-air processing vats containing the leaves. He noted that during processing, the coca leaves are placed in cement or plastic-lined vats containing kerosene and sulfuric acid. The leaves must then be crushed, usually by people stepping on them in a manner similar to the procedure used to crush grapes during wine making. These reagents in the vat then remove the alkaloids from the crushed leaves. Once that process is completed, the liquid mixture is poured into other vats filled with limestone to neutralize the acetic solution. That harsh treatment, Stanley suggested, was responsible for the damage to the pollen found in that first group from the cocaine sample. He said that he was unable to determine the time of year when the coca paste may have been prepared, but he noted that he did find a number of *Lycopodium* spores in the sample. Their presence, he suggested, indicated a probable spring processing period because *Lycopodium* sporangia mature and open during the months of September–November in South America.

The second group of pollen types in the sample consisted of pollen taxa found in a Sub-arctic environment and included pollen grains from jack pine (*Pinus banksiana*) and Canadian hemlock (*Tsuga canadensis*). These two trees commonly grow together in only a few regions of North America, thus their pollen could be used to infer that the cocaine was smuggled into North America at some location where jack pine and Canadian hemlocks are common. Stanley suspected that after the cocaine paste was smuggled into North America from its origin in South America it was "cut" at its point of entry into North America. That is how and when the jack pine and Canadian hemlock pollen probably entered the cocaine sample. Although jack pines and Canadian hemlocks occupy a thin ecological band along the US–Canada border region from northern Wisconsin eastward to the mountains of western Maine, the suspected method of entry was probably by airplane from South America. Although Stanley did not suggest a precise entry point, there are many plane flights from South America to the city of Montreal each day and that city is often the target of smugglers. Montreal is also one of the few large metropolitan areas within the jack pine and Canadian hemlock zone.

Stanley suggested that the final group of pollen grains came from a variety of weedy plants and trees that commonly grow in vacant lots and parks throughout the city of New York. The weedy pollen and tree taxa in the sample included various species of composites, chenopods, grasses, oak, and birch. Like the jack pine and Canadian hemlock pollen, Stanley suspected that the pollen in this last group probably entered the sample when the cocaine was cut again in New York City before being prepared for final distribution.

A third forensic pollen case during the 1990s took place in Texas. A policeman from East Texas asked for help in the investigation of a serial murder case. The bodies of five young women had been found in shallow graves in a vacant field not far from a major city. Most of the victims had been buried nude or wrapped in sheets. Unfortunately, we were not contacted until after the initial and excavation phases of the investigation.

The bodies were in various stages of decomposition and while attempts were being made to identify the victims, we suggested that pollen trapped in hair samples might provide some clues. Hair samples from three of the victims were removed and sent for analysis. Pollen trapped in the victims' hair might provide clues as to where they had lived prior to being killed and buried in the vacant field. Control samples were collected from the soil in the shallow graves and from several surfaces areas of the vacant field. The pollen in those control samples were used for comparisons with the pollen recovered from the victims' hair samples.

The area where the bodies were found is within the western edge of the Eastern Deciduous Forest, but large areas of the forests in East Texas were cut for timber during the 1800s and 1900s. Much of that cleared region was replanted with fast-growing pine forests that are now logged about every 20–25 years for timber. The control samples from surface and grave sites were heavily dominated by diploxylon pine pollen (i.e., from *Pinus taeda*, *P. echinata*, and *P. palustris*). In addition, the samples contained lesser amounts of pollen from various grasses, composites, oak, hickory, and traces of magnolia, sumac, and dogwood. Forensic pollen samples examined from the hair samples contained almost the identical mixture of pollen types found in the control samples from the grave and nearby surface sites. None of the pollen types in the hair samples were from taxa found outside the Coniferous–Deciduous Forest mixture that now grows in that region today.

When the study was completed, it was concluded that the pollen found in the victims' hair either confirmed that they had been abducted from locations within that general region, or that the pollen grains found were contaminants that came from the soils in which the bodies had been buried.

The last forensic case examined during the 1990s pertained to a shipment of Native American artifacts that were seized at a USA border entry point. During the late 1990s, a routine vehicle inspection at the Texas/Mexico border revealed several boxes filled with artifacts. These included hand made sandals woven from the fibers of lechuguilla (*Agave*) and sotol (*Dasylirion*), fiber cordage, woven baskets, projectile points, woven mats, and other artifacts similar to ones that have been found in archaeological sites along the Texas/Mexico border region dated to periods between 2000 and 6000 years ago.

The person driving the vehicle claimed that the artifacts were found in caves on his West Texas ranch and that he had taken the artifacts to Mexico to have them identified and appraised. If that were true, the artifacts would legally belong to him and no crime would have been committed. However, if the artifacts were of Mexican origin and were being removed illegally from that country without the government's permission, then that would be a crime. The artifacts were confiscated and sent to Texas A&M University where archaeologists examined the artifacts and acknowledged that they were similar to ones that have been recovered from archaeological sites in both northern Mexico and West Texas. Based on the shape and composition of the artifacts, archaeologists admitted that the artifacts could easily have come from either area since prehistoric groups often wandered back and forth across the Rio Grande River region that now marks the border between Texas and Mexico. Next, some of the dirt attached to many of the artifacts was carefully removed and examined. A pollen analysis of the dirt revealed that many of the pollen types in those samples were types commonly found in areas of both West Texas and northern Mexico. The collected pollen data were then compared to pollen data available from soil surface samples in various regions of West Texas and pollen records from the soils of prehistoric archaeological sites in West Texas. Unfortunately, surface or archaeological soil samples could not be obtained from regions of northern Mexico where the artifacts may have originated.

The soil samples from the artifacts contained higher percentages of pollen from arboreal and riparian vegetation than any of the prehistoric or modern soil samples from West Texas. Although we could not be certain, due to a lack of comparative samples from Mexico, we nevertheless reported that the artifacts were most probably removed from sites in northern Mexico rather than from caves on the defendant's property in West Texas.

2.4. The present

In spite of all the efforts during more than three decades to convince law enforcement agencies in the USA to consider using pollen as a forensic tool, little progress has been made. Repeated presentations to law enforcement agencies, to the faculty and students of major universities, and to various professional organizations that offer training in security and/or forensics have had little effect. Articles have been written on the topic for professional journals, newspapers, and popular magazines. None of this seems to have made any difference.

Unlike the growing use of pollen evidence in criminal cases in other countries including New Zealand, the United Kingdom, and Australia, law enforcement agencies in the USA have virtually ignored attempts to use forensic pollen studies. We are not certain why this seems to be the case, but we can suggest a few possible reasons based on our conversations with some law enforcement agents.

One aspect that seems to be a problem is the collection of appropriate pollen samples for forensic studies. Proper sample collection is always a key focal point of our oral and written presentations. Copies of sampling procedures have been sent to a number of forensic labs and law enforcement agencies. Nevertheless, most of the enquiries from law enforcement agencies asking about the merits of using pollen studies for a specific case are focused on two aspects. First, in most cases, all other attempts to solve the case have failed and as a last resort someone suggested they might want to try pollen evidence. Second, whatever items these agencies have retained from previous crime scenes, including clothing, vehicles, and weapons, have generally been compromised by the agency's failure to prevent subsequent pollen contamination. All too often the caller is informed that their samples, which were collected improperly, or which have been contaminated since collection, are of minimal or no value. Even though the lectures and written articles recommend it, law enforcement agencies in the USA have yet to seek the advice of a forensic palynologist immediately *after* a crime is committed and at a time when samples need to be collected. Unfortunately, there is little value in examining samples that cannot be used in court as evidence because of improper collection procedures, because of possible post-collection contamination, or because the samples have an unclear history of where they have been stored from the time of collection until they were analyzed.

A second reason why forensic pollen studies seem to be rarely used in the USA pertains to the history of their use in the USA court system. Because forensic pollen evidence has been so rarely used in the USA, there is little precedence for its use. As a result, law enforcement personnel, and often judges, seem reluctant to place confidence in its use. Some lawyers and law enforcement agencies have admitted that they are not convinced that pollen evidence could be used successfully as compelling evidence in a USA court. Furthermore, because very few law enforcement agencies have ever heard of forensic pollen studies, they are often skeptical and do not see the need to collect appropriate samples at a crime scene or to seek the help of someone trained in this field of study. What is needed is a dramatic, high-profile court case in the USA in which pollen evidence plays a significant role in convicting, or confirming the innocence of, a defendant on trail. That type of publicity might change the views of many lawyers and law enforcement agencies, and it might encourage them to consider pollen studies for future cases.

A third problem, reported by some law enforcement agencies, is a lack of specialists in the USA who are trained and willing to conduct forensic pollen studies. This is a serious problem because there are less than one-half dozen palynologists in the USA who have ever had experience working in the field of forensics. Furthermore, all of those palynologists have full-time jobs that focus on doing non-forensic research or teaching, or both. For example, I (Bryant) teach full time. Because of my teaching schedule I am rarely able to be absent from my classes for more than 2–3 days at a time during any semester. Likewise, I (Jones) have a full-time, non-forensic, research position working on numerous projects for the USDA. As such, I can rarely devote more than a few days at a time to outside research activities (i.e., forensic cases).

Lack of full-time employment opportunities for forensic palynologists in the USA severely limits the time and effort any of us can devote to forensic work. In the past, even when asked to assist some law enforcement agency, the few forensic-trained palynologists are unable to help due to their work commitments. On at least three recent occasions during the past 2 years we have been contacted by law enforcement agencies and asked to assist them in the investigation of a murder case, each of which was in an out-of-state location. Unfortunately, because of our teaching and research responsibilities, we were not able to pursue the needed field investigation or conduct the type of background research that was needed. Even when we have time to work on cases with nearby agencies, later we face the problem of having to be away from our jobs to testify.

Fourth, even among those few USA palynologists who are trained in forensics, there is a question of personal liability, the problem of being bonded, and for most, a lack of experience in testifying in court. This aspect is a major concern some of the individuals questioned. They admit that they are unwilling to have their personal lives and/or their reputations ‘‘put on trial’’ and to be subjected to brutal questioning or accusations of poor scientific research during cross-examinations. Often, cross-examinations can be a devastating experience for a scientist who may not be accustomed to having his or her personal life, education, research methods, or scientific expertise drawn into question. Also, some are shocked to be told that their data may be inadmissible because of some minor technicality. Contrary to what a forensic palynologist may believe, a court is *not* where one arrives at the truth. Instead, the sole purpose of court testimony is to ensure that the prosecution has prepared an ‘‘airtight’’ case, has established their case ‘‘beyond a reasonable doubt,’’ and that the rights of the defendant have not been compromised.

A fifth problem facing the use of forensic palynology in the USA is the reality that there is no major university or other type of training facility that offers specific training in pollen forensics. The primary reason for this lack is the unavailability of job opportunities for graduates. Not only is there a lack of training facilities, but there is also a lack of appropriate pollen research facilities where forensic pollen samples could be examined. Forensic pollen studies must be conducted in a sterile facility that has areas where samples can be stored in secure safes or in locked areas where only the forensic palynologist has access. After working on a forensic pollen sample, the researcher must be able to assure the court that the forensic pollen samples were securely stored under lock and key at all times and that there were no opportunities for tampering or contamination of such samples. In addition, many facilities the lack the special types of equipment needed for processing and examining very small forensic pollen samples. Some facilities also lack top-quality optical microscopes and some do not have access to scanning electron (SEM) and transmission electron microscopes (TEM), should they be needed. Finally, to prevent accusations that a sample may have been mixed during processing or mislabeled, elaborate steps may be required to convince the court that such accidents did not occur.

Sixth, conducting forensic pollen studies requires adequate modern pollen and spore reference materials and slide collections. Because there are hundreds or even thousands of potential plant taxa that might exist in any forensic pollen sample, precise identification of pollen types is often time-consuming and difficult. Although many palynologists may have access to limited numbers of pollen and spore taxa in reference collections, not all palynologists have access to vast collections that encompass a broad range of pollen types found in many different geographical regions. In addition, internet web sites, computer databases of pollen types, published pollen keys and atlases, and pollen taxonomic reports published in journals and books are vital essentials needed to conduct forensic pollen studies.

A seventh problem is funding. In the USA, the few palynologists who occasionally conduct forensic studies are full-time employees of private, state, or federal agencies. As such, there is often a problem of how the palynologists, or their employer, can recover the costs for outside forensic studies. In addition, we have found that all too often, law enforcement agencies asking for forensic pollen studies are not always able or willing to commit their limited funds to pay for techniques that some consider ‘‘untested in court.’’

3. Summary

From the discussion of current problems and resistance for using forensic pollen data in the USA, one might think the future for this discipline in the USA is bleak. We would like to believe this is not true, and that soon law enforcement agencies in the USA will recognize the potential usefulness of collecting pollen data from crime scenes and for using it as a forensic technique.

Certainly there have been other countries, similar to the USA, where forensic pollen studies have also languished. However, in some of those other countries there has been a dramatic change in their attitudes during the past few decades. Prior to the forensic work by palynologist Dallas Mildenhall during the 1980s, forensic palynology in New Zealand was virtually unknown, yet today it has become a routine technique throughout New Zealand [82]. Similarly, in the United Kingdom (UK) forensic palynology was a little-used technique until very recently, as discovered in the 1990 survey [91] of major UK forensic labs. However, during the 1990s and through the present, the extensive work by forensic palynologist Patricia Wiltshire [92] has encouraged many law enforcement agencies throughout the UK to consider pollen evidence as a powerful tool, which is proving to be useful in a wide range of criminal cases. Finally, in Australia the application of forensic palynology was little known and little appreciated until Bruce and Dettman [81] published an article pointing out the vast potentials for its use in Australia. Since then, forensic palynologist Lynne Milne has maintained an active forensic pollen program in Western Australia [93,94] where she has convinced many law enforcement agencies about the importance of collecting and examining pollen as part of a crime scene's evidence. Similar testimonies to the growing importance placed on the use of forensic palynology also exist for other countries as well.

The world has become a dangerous place to live as the 21st century begins. Rapid communication, easy and quick travel across continents, the continuing rise in the use of illicit drugs, and acts of international terrorism have each placed a premium on our safety. One of the effective ways to deal with these growing problems, and to make the world safer, is to find new and more effective ways to outwit criminals and catch terrorists before they can commit terrible acts, such as the bombing of the World Trade Center in New York City. Although the use and application of forensic palynology in the USA and elsewhere will not solve all of these problems, it can, nevertheless, become one of the important tools that could be used effectively to make us all safer.

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